NASA TN D-213

7N-05
197745
18 P.

TECHNICAL NOTE

D-213

DYNAMIC MODEL INVESTIGATION OF A

LANDING-GEAR CONFIGURATION CONSISTING OF

A SINGLE MAIN SKID AND A NOSE WHEEL

By Stanley Faber

Langley Research Center
Langley Field, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON February 1960

1G

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-213

DYNAMIC MODEL INVESTIGATION OF A LANDING-GEAR CONFIGURATION CONSISTING OF A SINGLE MAIN SKID AND A NOSE WHEEL

By Stanley Faber

L
6
7
4

SUMMARY

An investigation has been made of the directional stability during the landing ground run of a skeletonized dynamically similar model of an airplane having a landing gear consisting of a single main skid, a castering nose wheel, and limber wing skids. The tests were made by towing the model on a moving-belt runway at a constant belt speed. Variations in nose-wheel shimmy damping and in nose-wheel skid geometry were tested.

The results indicated that the nose wheel could cause directional instability unless the destabilizing forces and moments produced by the wheel when at an angle to its direction of motion were kept to a minimum. Nose-wheel steering and forms of shimmy damping other than viscous damping about the strut axis were found to produce stable configurations.

INTRODUCTION

Skid landing gears, because of weight and volume considerations, have been and are being proposed for airplanes. This statement is especially true for the rocket-powered research airplane, an airplane characterized by relatively few landings during its lifetime and by the fact that normal take-offs are not generally required. Skid landing gears, however, pose several new problems. One of the basic problems is directional stability during the ground run after the high-speed landing as shown by the direction oscillation of the landings reported in reference 1 and by unpublished data.

In a landing-gear arrangement consisting of a skid or skids rearward of the center of gravity and a nose wheel forward of the center of gravity, restraint of the free castering action of the nose wheel may cause either a statically divergent motion or a divergent oscillation of the airplane. However, some restraint of the castering action of the nose wheel is required to prevent shimmy. With the skid landing gear, the pilot does not have the capability of steering the airplane by use of differential braking action as in a normal tricycle landing gear.

In order to investigate some of the directional-stability problems, a brief series of qualitative tests was made of a typical skid configuration. The tests were made by "towing" the model on a moving-belt "runway" to simulate the conditions existing at some point in the landing run of a full-scale airplane. In the tests, variations in nose-wheel skid geometry and variations in nose-wheel shimmy damping were investigated. These results are presented herein. A similar investigation in which the model was catapulted across the ground to study the landing-run characteristics is reported in reference 2. This study was made concurrently with the investigation reported herein.

MODEL AND TESTS

The tests were made by towing a dynamically similar model of an airplane equipped with a skid landing gear on the moving-belt runway. Both the model and the airplane were assumed to be rigid bodies. The model was a skeletonized model with lead weights arranged to provide the proper center-of-gravity location, the desired moments of inertia, and the correct scale weight. Figure 1 is a photograph of the model on the belt runway, and table I gives the pertinent characteristics of the model and of the full-scale airplane. Figure 2 is a drawing of the model. The linear dimensions of the model were scaled by a factor of 50, whereas the weight was scaled by the cube of this factor and the inertias were scaled by the fifth power. The belt speed was scaled by the square root of 50.

As can be seen in the photograph in figure 1, the landing-gear arrangement consisted of a single main skid, a full-swiveling castering nose wheel, and limber wing skids. The skid was a flat piece of steel with a large leading-edge radius and with all other edges rounded; it was free to rotate only in the vertical plane of symmetry. The nose wheel was a miniature ball bearing with a rubber "O" ring cemented to the outer race. The nose-wheel strut was supported by a similar miniature ball bearing to keep friction to a minimum. Limited tests were made of a steel nose wheel, that is, without the "O" ring tire. Limber cantilever springs were attached to the "wing" to provide some mechanical roll stabilization. The tow point on the model was at the center of gravity, and the length of the towline, a nylon thread, was approximately 10 times the wheelbase of the model.

The runway was an endless belt made of cloth impregnated with rubber-base cement and sanded to a smooth finish. The coefficient of friction between the belt and the skid was approximately 0.25. This value is of the same order as the estimates from actual landings as reported in reference 1. For most of the tests the belt speed was a constant 12 knots, corresponding to a full-scale speed of 87 knots.

The various model configurations tested are listed in table II. These include the "basic" configuration and configurations incorporating variations in the stiffness of the roll-stabilization springs, variations in shimmy damping, variations in center-of-gravity and of skid location, steel and rubber-tired nose wheels, and nose-wheel centering and steering. Also, a series of tests was made of a model with the skids forward of the center of gravity and with a tail wheel.

Two sets of roll-stabilization springs were tested, a stiff set that produced a rolling-motion period of 0.2 second and a limber set that produced a period of 0.43 second. The roll damping ratio for either set was 0.15 (one-half amplitude in three-fourths of a cycle). The variations in nose-wheel shimmy damping were obtained by applying oil or grease to the ball bearing which supported the nose-wheel strut. The oil or grease acted as a viscous damper on the rotations of the strut. The damping referred to as heavy viscous restraint was that sufficient to remove all traces of shimmy at the maximum belt-speed condition. A second form of shimmy damping was also tested, damping as produced by a dynamic vibration absorber. This type of damping differed from the viscous damping in that no energy from the shimmy vibration was transferred through the damper to the body of the model. The energy instead was transferred into a vibration of a mass spring system that constituted the absorber. The vibration absorber used in these tests was a thin strip of spring steel that was attached to the wheel axle. The length, or natural frequency, of the strip needed to provide effective damping was experimentally determined. A sketch of the absorber is shown in figure 3(a).

Steering of the nose wheel by means of a manually controlled electric torque motor was tried and found not practical because of the short period of the model oscillation. However, the principle of nose-wheel steering was tested by use of a parallel linkage attached to the model at the center of gravity that maintained the alinement of the nose wheel with the direction of motion. A sketch of the linkage is shown in figure 3(b). The skid-forward tail-wheel tests were made with the model towed backwards and the skid sufficiently forward of the center of gravity so that the tail wheel would always be in contact with the belt. These tests covered various modifications of the tail wheel including spring centering, heavy viscous shimmy damping, and a combination of both of these modifications.

RESULTS AND DISCUSSION

The various model configurations were evaluated by repeated observations of the motions of the model following release from a straight and level position while in contact with the belt. Time histories of the lateral displacement of the center of gravity and of the yaw angle are shown in figure 4 for a typical test. As can be seen, this configuration (number 1 of table II) is unstable; that is, the yaw angle approximately doubles in amplitude in each succeeding cycle. The track of the center of gravity shows a similar divergent oscillation. The figure shows that the yaw angle leads the center-of-gravity motions by approximately 90°.

L
6
7
4

Because of the qualitative nature of this investigation and because the data concerning the angular displacement and position could be determined only approximately and with great difficulty from the motion pictures of the tests, no time histories of the results other than those shown in figure 4 are presented. The results are, instead, summarized in table II and are discussed further in the following paragraphs. Also, a motion-picture film supplement covering the model motions exhibited by each configuration tested has been prepared and is available on loan. A request card form and a description of the film will be found at the back of this paper on the page immediately preceding the abstract and index page.

The contribution of the rolling motions to the directional stability was investigated by testing two different sets of roll-stabilization springs. The limber set allowed considerable rolling motion, and the stiff set all but eliminated rolling motions. The tests labeled "configurations 1 and 2" compare these springs and, as can be seen, the stiffness and hence the rolling motions had no noticeable effect on the directional stability.

The mechanism producing the oscillation was deduced to be similar to that involved in the snaking of an airplane which is caused by a free rudder with friction in the rudder hinge. In the case of a rear rudder, the rudder must float against the relative wind to cause instability. If the rudder were ahead of the center of gravity, however, a tendency to float with the relative wind (with hinge friction) would produce snaking. This latter case is analogous to the castering nose wheel, again with hinge friction. The nose wheel, when at an angle to its direction of motion, produces a side force and a drag force that are analogous to the lift and drag of a lifting surface at an angle of attack. If the castering were perfect (no frictional forces either static or viscous and no inertial forces), the side-force component from the nose wheel would be zero and the drag force would come from rolling friction and would be small. If the castering were not perfect as a result of static or viscous friction, a side-force component would be present and, further, the drag force would be increased by some sliding friction. For a nose wheel, the drag force would produce a static destabilizing moment when the vehicle is yawed. At the same time, the side-force component would produce a moment in phase with the angular velocity of the vehicle and, therefore, would feed energy into any yawing oscillation. For a vehicle with a skid landing gear, the problem is aggravated by the additional down load on the nose wheel caused by the drag force of the skid. For the configuration of these tests, the nose-wheel load while "moving" was about 50 percent greater than the static load. These nose-wheel effects are opposed by the action of the drag force on the main skid. When the skid is rearward of the center of gravity, the skid produces a static stabilizing moment and also a small damping effect.

L
6
7
4

The directional-stability problem therefore appears to depend on the ability of the nose wheel to maintain alinement with the direction of motion. The basic nose-wheel configuration, a rubber tire with heavy viscous shimmy damping, was not able to maintain the alinement required as was shown in the tests of configurations 1 and 2. In both these tests the model underwent a divergent oscillation. The effect of reducing the shimmy damping to a moderate value and to zero is shown by configurations 3 and 4. At a moderate value of damping, the model could be made neutrally stable (at the normal belt speed of 12 knots). Some shimmy was present, but not enough to disturb the model. If, however, the belt speed were reduced, the model would experience a divergent oscillation similar to the heavy viscous damping case. With no damping at the normal belt speed, the nose wheel had excessive shimmy and the model underwent a static divergence. Configuration 5 shows that at very low speeds stable tests could be made with no shimmy damping. These tests lead to the conclusion that the amount of viscous damping (or restraint) as applied to the model in these tests should be reduced to zero as the speed is reduced. Reference 2 indicates a similar dependence of stability on the viscous damping of the nose-wheel shimmy oscillation.

The effects of a limited rearrangement of the center of gravity and of the skid were obtained in the tests of configurations 6, 7, and 8. These tests were somewhat inconclusive. Both moving the center of gravity rearward (configuration 6) and moving the skid rearward (configuration 7) tended to reduce the instability of the yawing oscillation. Lowering the center of gravity (configuration 8) had a destabilizing effect on the oscillation. In the rearward center-of-gravity case, the result was thought to be due to the reduction in the nose-wheel load and, therefore, in the destabilizing moments from the nose-wheel drag. In the rearward-skid case, although the nose-wheel load increased somewhat, it was thought that the stabilizing and damping moments produced by the drag of the main skid increased by a greater amount.

The effects of a limber centering spring on the nose wheel and of a noncastering nose wheel are shown by the tests of configurations 9 and 10. Both of these configurations are more unstable than the basic case. In particular, the noncastering configuration exhibited a rapid static divergence.

In an effort to reduce the destabilizing moments from the nose wheel, a steel wheel was tested with various amounts of viscous restraint on the castering hinge. The use of a steel nose wheel might not be practical for the assumed full-scale airplane of these tests; however, the tests of the steel wheel contributed toward understanding the problem. Configurations 11, 12, and 13 were tested with increasing amounts of damping, and configuration 14 was tested with heavy viscous restraint at slow belt speed. The zero-damping configuration (11) was stable and exhibited no oscillatory characteristics. The nose wheel shimmied throughout the test, but because of the smooth, hard surface of the wheel, the resulting friction forces were low and did not disturb the model. When damping was added to reduce the shimmy (configuration 12), the stability was reduced. The heavy-restraint configuration (13) was only neutrally stable, and at the low belt speed it was unstable. The foregoing effects of shimmy damping might be explained as follows: When the wheel shimmies freely, the side-force components due to the high-frequency shimmy motions tend to have no effect on the yaw oscillation of the model. The drag force of the wheel, however, is increased by the shimmy motions. For a steel nose wheel the total drag force and, therefore, the destabilizing moments would be somewhat less than the stabilizing moment of the main skid. When there is viscous restraint and no shimmy, the side forces are present. As mentioned before, the phasing of the side-force components is such as to feed energy into an oscillation. The more shimmy damping in the nose-wheel strut the greater the destabilizing moments.

The results of maintaining the nose wheel alined with the direction of motion through use of nose-wheel steering are shown by the test of configuration 15. In this test the nose wheel introduced no destabilizing moments. Even when intentional disturbances in yaw were given the model, no oscillation occurred, with the model rapidly damping to a steady-state condition. Although "perfect" steering would be required to duplicate these results full scale, it is thought that some deterioration in steering could be tolerated before the configuration would be unstable. It is therefore concluded that a pilot or, in the case of short-period oscillations too fast for a pilot to control, a simple autopilot could satisfactorily steer the nose wheel. For the characteristics of the full-scale airplane of these tests, the period would be 7 or 8 seconds and, therefore, well within the ability of a pilot to maintain control.

Shimmy damping of a different form from viscous damping about the castering hinge was tested by configuration 16. In this test the dynamic vibration absorber described earlier was used to supply shimmy damping. This damper gave neutrally stable tests with $\pm 3^{\circ}$ of yaw oscillation at a belt speed of 12 knots and a much smaller amplitude oscillation at reduced belt speeds. Another type of shimmy damping that differs from viscous damping about the castering hinge is that produced by corotating dual wheels. Corotating dual wheels have an effect similar to the dynamic vibration absorber in that they tend to absorb the energy of the shimmy oscillation instead of transferring the energy to the body of the vehicle. Recent unpublished data indicate that this type of nose-wheel configuration could produce a stable-airplane configuration.

The skid-forward configurations showed that with only spring centering on the tail wheel (configuration 17) the model was stable. However, the test also showed that considerable rolling and yawing motions were present. With only viscous damping on the castering hinge (configuration 18) the model was statically unstable. With both centering and damping (configuration 19) the model was stable in both roll and yaw.

CONCLUDING REMARKS

An investigation has been made of the directional stability during the landing ground run of a skeletonized dynamically similar model of an airplane having a single main skid, a castering nose wheel, and limber wing skids. The tests were made by towing the model on a moving-belt runway at a constant belt speed.

The results indicated that the nose wheel could cause directional instability unless the destabilizing moments from the side force produced by a wheel at an angle to its direction of motion and from the drag of a wheel in a similar yawed condition were kept to a minimum. In order to keep these moments at a minimum, the wheel should be kept alined with the direction of motion. The tested rubber-tired nose wheel was not able to maintain the alinement required. With viscous damping to remove or control nose-wheel shimmy, the model was dynamically unstable, the oscillation doubling amplitude each cycle. With no shimmy damping the rubber-tired model was statically unstable, the shimmy causing a rapid divergence. A number of variations in the basic configuration were also found unsatisfactory or insufficient in improving the directional stability. These configurations included limited relocation of the center of gravity and of the skids, spring centering of the nose wheel, and a noncastering nose wheel.

A steel nose-wheel configuration was found satisfactory for the model tests but might not be practical for a full-scale airplane. The model was directionally stable only when the nose wheel was allowed to shimmy excessively. When viscous shimmy damping was added to the strut, the model stability was reduced.

Nose-wheel steering, that is, maintaining the alinement of the nose wheel with the direction of motion by mechanical means, was found very satisfactory. Although the period of the yaw oscillation of the model was too short to allow manual steering, the longer periods of the yaw oscillation of a full-scale airplane would allow a pilot to steer the nose wheel with a minimum of effort.

The principle of shimmy absorption through means other than viscous damping about the strut axis also proved successful. In this test a model with a dynamic vibration absorber on the nose wheel maintained the model to a small-amplitude, neutrally stable oscillation.

The stability of a skid-forward tail-wheel configuration was also investigated. These tests showed that a model with a tail wheel having both spring centering and viscous shimmy damping would be stable in all modes of oscillation.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., October 16, 1959.

REFERENCES

1. Day, Richard E.: Measurements Obtained During the Glide-Flight Program of the Bell X-2 Research Airplane. NACA RM L53G03a, 1953.

2. Deutschman, Jerome N., and Schlessinger, Monroe: Dynamic Model Tests of an Unconventional Landing Configuration. Proc. Nat. Specialists Meeting on Dynamics and Aeroelasticity (Fort Worth, Texas), Inst. Aero. Sci., Nov. 1958, pp. 128-135.

L
6
7
4

TABLE I

DIMENSIONS OF THE BASIC-MODEL CONFIGURATION

	Model	Full scale
Wheelbase, nose-wheel strut to skid strut, in.	4.04	202
Skid width, in.	0.2	10
Skid length, in.	0.92	46
Span of roll-stabilization springs, in. . .	3.18	158.8
Nose-wheel caster offset, in.	0.1	------
Nose-wheel diameter, rubber tire, in. . . .	0.4	------
Center-of-gravity location, in.:		
Rearward of nose-wheel strut	3.5	176
Above ground plane	1.00	50
Weight, lb	0.088	11,000
Inertia in yaw, slug-ft^2	10.6×10^{-5}	33,100
Inertia in roll, slug-ft^2	2.22×10^{-5}	6,900
Inertia in pitch, slug-ft^2	8.88×10^{-5}	27,700

TABLE II

CHARACTERISTICS OF MODEL CONFIGURATIONS TESTED

Configuration	Shimmy damping	Roll springs	Other changes from basic configuration	Shimmy	Stability	Damping, cycles to half or twice amplitude	Remarks
1	Heavy viscous	Stiff	Basic configuration	None	Unstable	1	Shown in figure 4
2	Heavy viscous	Limber	None	None	Unstable	1	Considerable rolling motion
3	Moderate viscous	Limber	None	Some	Neutral	-----------------	10° yaw oscillation
4	None	Limber	None	Considerable	Unstable	Static divergence	Rapid translation off belt runway
5	None	Limber	Slow speed	None	Stable	Nonoscillatory	
6	Heavy viscous	Stiff	Center of gravity moved rearward to 4.04 inches	None	Unstable	3	Some tendency for nose wheel to lift from belt
7	Heavy viscous	Limber	Wheelbase increased to 4.9 inches	Occasional	Neutral to unstable	3 to 4	Neutral for first 8 seconds, then unstable
8	Heavy viscous	Limber	Center of gravity lowered to 0.75 inch	None	Unstable	1/2	
9	Heavy viscous	Limber	Limber centering spring on nose wheel	None	Unstable	1/2	
10	Noncastering	Limber	None	None	Unstable	Static divergence	Very rapid yaw divergence
11	None	Stiff	Steel wheel, 0.3-inch diameter	Considerable	Stable	Nonoscillatory	
12	Moderate viscous	Stiff	Steel wheel	Occasional	Stable	4	
13	Heavy viscous	Stiff	Steel wheel	None	Neutral	-----------------	
14	Heavy viscous	Stiff	Steel wheel, slow speed	None	Unstable	1/2	
15	Heavy viscous	Limber	Nose-wheel steering	None	Stable	1	
16	Dynamic vibration absorber	Limber	None	None	Neutral	-----------------	3° yaw oscillation
17	None	Limber	Skid forward, centering spring on tailwheel	None noted	Stable	-----------------	Considerable rolling and yawing oscillations
18	Heavy viscous	Limber	Skid forward	None	Unstable	Static divergence	
19	Heavy viscous	Limber	Skid forward, centering spring on tailwheel	None	Stable	-----------------	Very stable about all axes

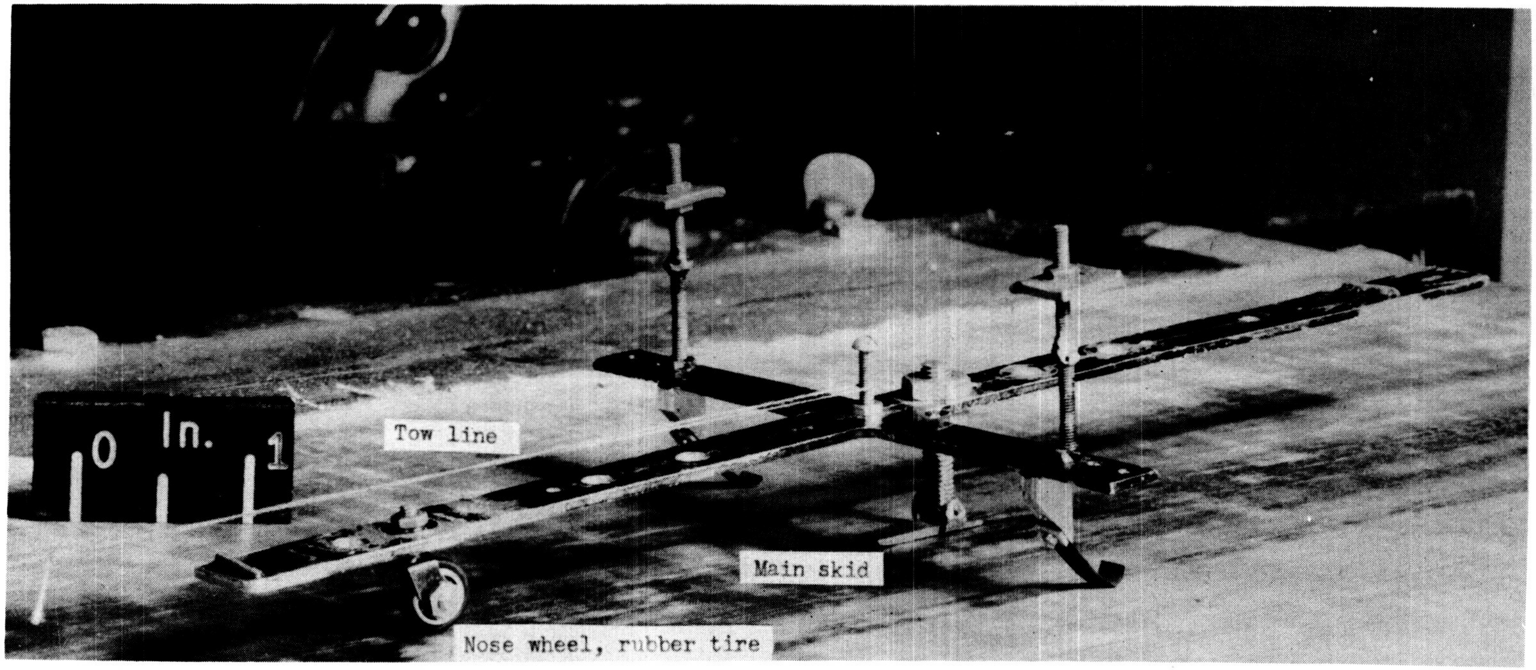


Figure 1.- Photograph of model on belt runway. L-90078.1

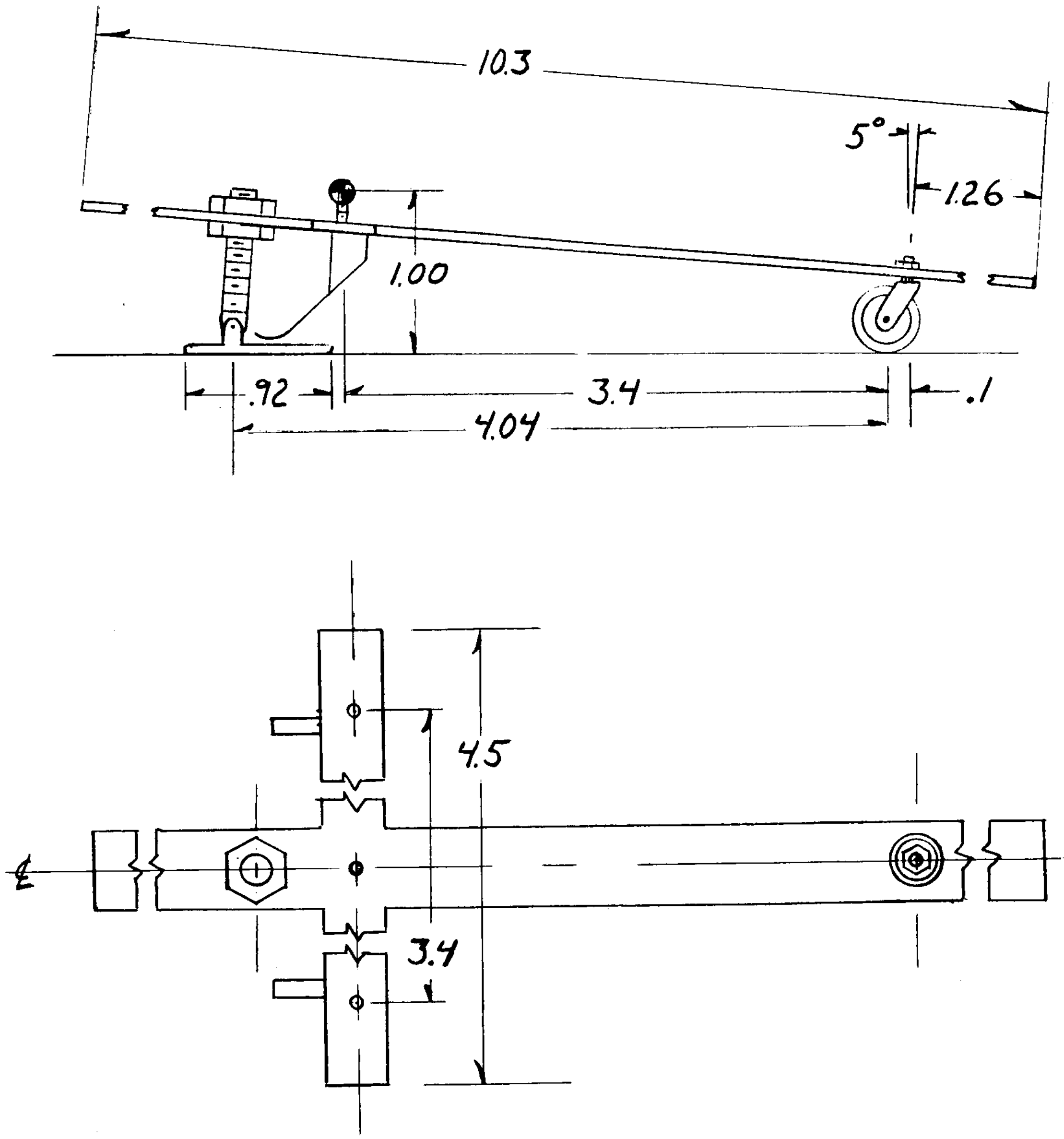
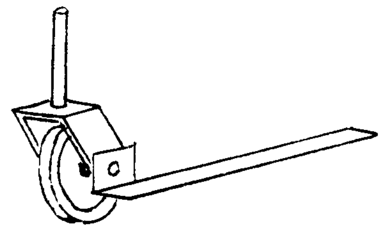
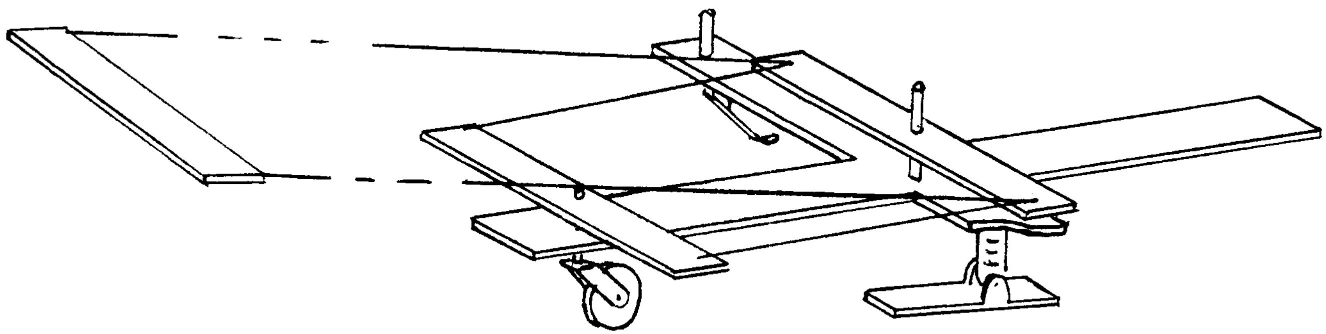


Figure 2.- Drawing of model. Dimensions are in inches.

L-674



(a) Dynamic vibration absorber.



(b) Parallel steering linkages.

Figure 3.- Mechanical devices tested on model. Drawing not to scale.

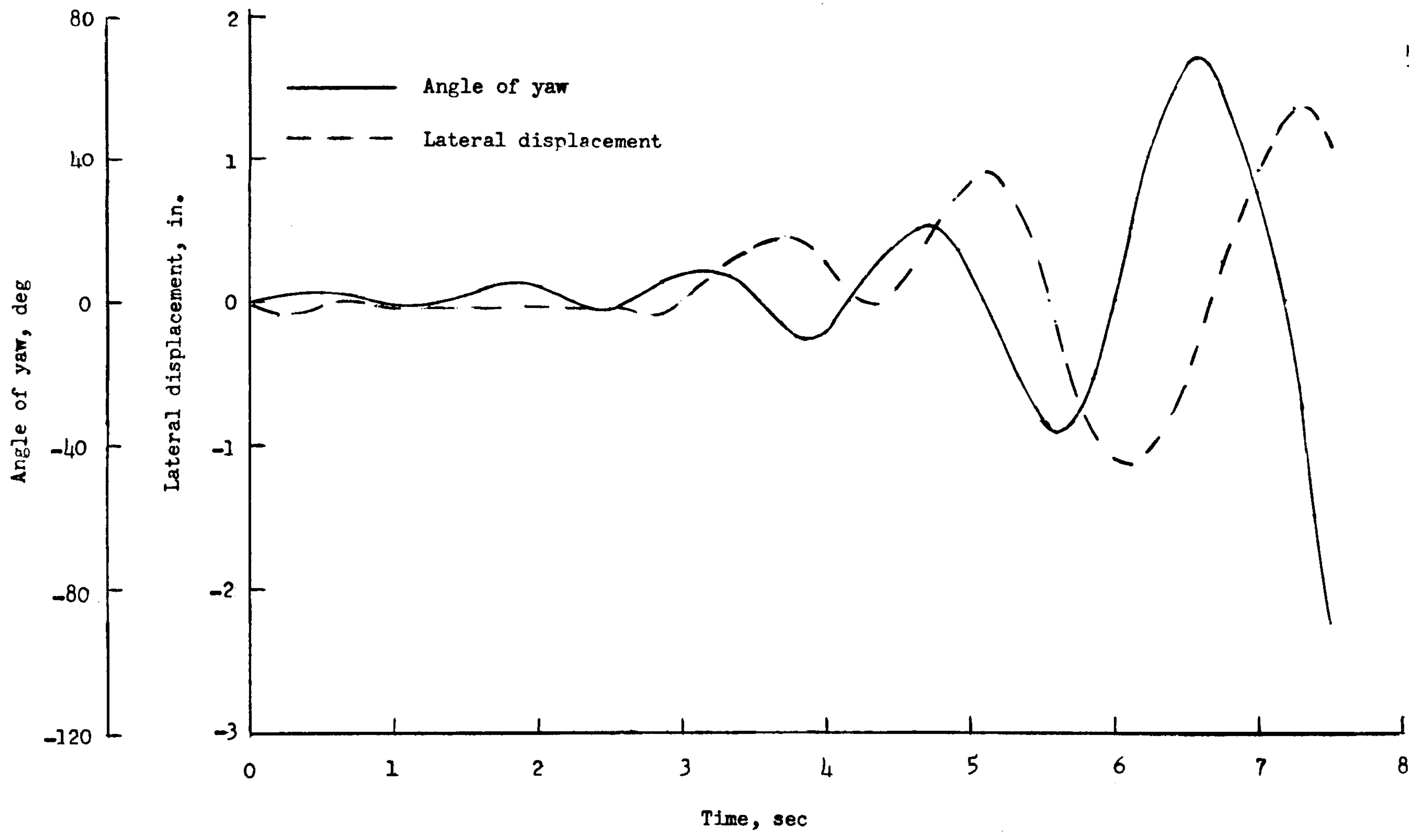


Figure 4.- Typical time history of model following release.
Configuration 1.